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DIVISION OF ENGINEERING

June 30, 1990

Dr. Edwin P. Rood
Code 1132 F
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5000

Dear Sir:

RE: ONR Grant N00014-90-J-1430 "Studies of Nonlinear Instabilities of Developing Wake Flows Behind Bluff Bodies and Their Control" J.T.C. Liu, Principal Investigator
Progress Report for March 15, 1990 - June 14, 1990

The general ideas of our approach to developing wake flows behind bluff bodies are reported by J.T.C. Liu in an invited paper at the Symposium on Turbulence Theories and Models Incorporating Experimental and Computer Simulation Knowledge of Coherent Structures, 11th U.S. National Congress in Applied Mechanics, Tucson May 21-25, 1990: "Possibilities of incorporating coherent structure models in turbulent shear flow calculations", Applied Mechanics Review vol. 43, no. 5, Part 2, May 1990, pp. S210-S213. This work directly attributes the nonuniversality of different classes of turbulent shear flows to the nonuniversality of hydrodynamical instability mechanisms of shear flows, which in turn give rise to coherent structures. Thus, issues specific to flow configurations need to be addressed. The presence of coherent modes must necessarily be coupled to the local mean motion as well as to the fine-scale (broad-band) turbulence. The number and the nature of the coherent modes follow from local hydrodynamical stability considerations. Thus, in the search for interacting modes, we arrive at the basic two-dimensional frequency-fundamental (2,0) and frequency-subharmonic (1,0) modes, coupled to the first- and second-three dimensional frequency-fundamental [(2,1) and (2,2)] and the first-three dimensional frequency-subharmonic (1,1) modes. Three-dimensional modes are spanwise periodic and are interpretable as the result of oblique-wave interactions. The simple direct interaction between (2,0) and (1,1) modes was the subject of the experimental investigation of J.D. Krull and T.C. Corke (J.D. Krull, I.I.T. M.Sc. Thesis, 1989). The applications of our "general" theory is continuing.

Sincerely yours,

Joseph T. C. Liu
Professor of Engineering
Principal Investigator

Carl Cometta
Executive Officer
Division of Engineering

cc: ONR Resid. Rep./Cambridge
NRL/Washington
DTIC/Alexandria
ORA/Brown University

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relationship). The fine-scale turbulence is involved at two levels. One is the Reynolds averaged level, in which the fine-scale turbulence is characterized by its kinetic energy content across the shear flows. The other level is on the fluctuation-modulated level in which the conditionally-averaged quantities prevail. Namely, the fluctuation-modulated turbulent stresses. We again, from scale analysis, postulate that these stresses are the products of a shape function (to be solved locally from hydrodynamic stability-like transport equations), and nonlinear amplitudes comprising of the product of the turbulent kinetic energy content and the fluctuation amplitude.

Thus, the nonlinear interaction problem is reduced to first-order coupled nonlinear ordinarily differential equations for the five coherent mode amplitudes, the wake width and the fine-scale turbulence energy content. At a later time, the downstream development of the relative phases of the coherent mode could be accounted by their respective evolution equations.

The evaluation of the coefficients of the ordinary differential equations involves the shape functions postulated for the coherent modes, turbulence and mean wake flow. In the case of the coherent mode shape and modulated-tu rbulent stresses, a subset of linear ordinary differential equations need to be solved locally prior to evaluating the appropriate integrals that would give the coefficients of the nonlinear interaction equations.

Some of the integrals are being evaluated and "validated" against previous work on two-dimensional cases. Work in this direction is in progress. Some progress is reported by J.T.C. Liu at the IUTAM Symposium on Nonlinear Hydrodynamic Stability and Transition, Valbonne, France, September 3-7, 1990: "Phase volume representation of two-coherent mode transition to turbulence in a developing free shear flow," (to appear in a special issue of European Journal of Mechanics).

Sincerely yours,

Joseph T. C Liu
Professor of Engineering
Principal Investigator

Carl Cometta
Executive Officer
Division of Engineering

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STATEMENT "A" Per Dr. Edwin Rood
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TELECON 10/16/90 VG

By per call

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